Comparison Analysis of the Eastern Range False Cape 915-MHz Doppler Radar Wind Profiler

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1. Introduction

The United States Space Force (USSF) is responsible for space vehicle launches at its Eastern Range (ER), which includes the Cape Canaveral Space Force Station (CCSFS). Multiple systems are used to measure the atmosphere at the ER, including suites of Doppler Radar Wind Profilers (DRWPs) operating at 915 MHz that measure winds within the lowest few kilometers of the atmosphere. Observations of boundary layer winds can be used for multiple applications, including serving as input to toxic dispersion models and characterizing winds for low-level aborts. In fall 2020 the USSF requested NASA's Marshall Space Flight Center (MSFC) Natural Environments Branch (NE) to evaluate wind output from the False Cape (FC) DRWP system (MSFC NE 2021). In that analysis, it was found that data availability was low in the lowest few hundred meters of a profile, shown in Figure 1. To increase the available data, the USSF modified the quality control (QC) algorithm for the FC DRWP, which collected data from October 2020 to January 2021. In Fall 2021 the USSF requested NASA's MSFC NE to evaluate the modified QC algorithm by comparing the data processed by the modified method (referred to as beam data) to data processed with the original QC method (referred to as original data). This report describes the system and the analyses that MSFC NE conducted to compare the availability and quality of data from the two QC methods.

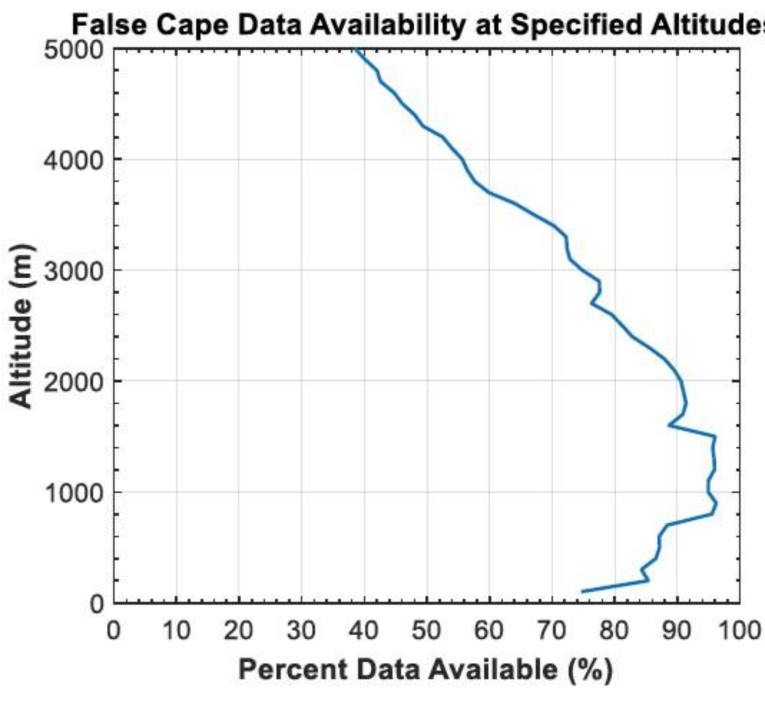

Figure 1: Percent of the False Cape DRWP archive that contains data records at discrete altitudes.

2. Instrumentation System

The following subsections describe data from the system that was utilized during this study. The CCSFS Weather Station provided MSFC NE with DRWP data via a secured data server. DRWP data was provided for the period of record (POR) dating from October 17, 2020 to January 26, 2021. Figure 2 displays the location of the DRWP.

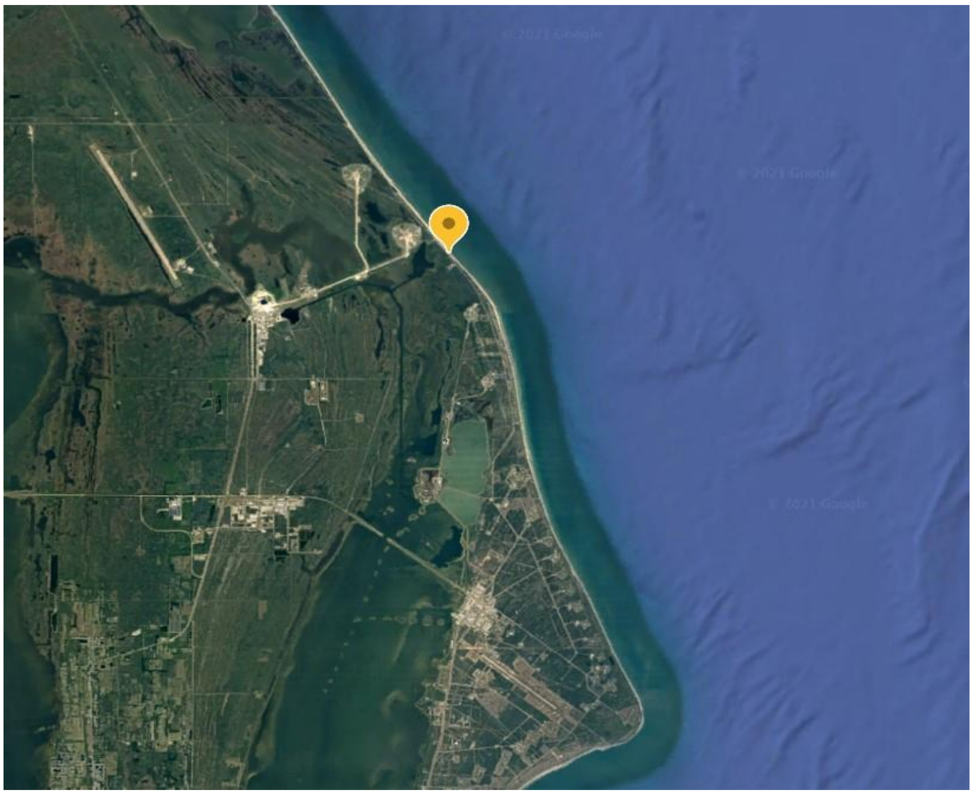

Figure 2: Location of the False Cape DRWP, denoted by the yellow pin.

2.1. 915-MHz DRWP

The DRWP derived boundary layer winds from 100 m to 5,000 m (328–16,404 ft) above ground level (AGL) in 100-m intervals.

3. Analyses

This section describes the methodology and results of the two analyses that MSFC NE conducted to evaluate the updated QC method. The first analysis consisted of assessing data availability versus altitude, which quantifies how much more data passed the checks contained in the updated QC method. The second analysis entailed comparing DRWP wind profiles from the original QC method to concurrent DRWP wind profiles from the updated QC method to quantify the differences between output generated by each method. Each subsection presents the analysis methodology and discusses results.

3.1. Data Availability

An analysis of data availability versus altitude was conducted for the FC DRWP data using both QC methods to show the probability of receiving vertically complete profiles within a specified altitude range. For this analysis, data availability was defined as 100% times the ratio of the number of profiles that contained data at all altitudes between the bottom of the profile and a given altitude to the total number of profiles collected.

Figure 3 shows the probability of a profile extending without gaps from the bottom altitude of 100 m (328 ft) to the selected altitude on the ordinate. One should interpret this figure as the percent of complete profiles from 100 m (328 ft) to the altitude specified on the ordinate, given that a profile existed. For the FC data using the original QC method (blue line), data availability was 75% at 100 m (328 ft) decreasing to 3% by 5,000 m (16,404 ft). For the FC data using the updated QC method (red line) data availability was 95% at 100 m (328 ft) decreasing to 20% at 5,000 m (16,404 ft), which denoted a 20% and 17% increase respectively from the original data.

Additional examination of data availability at discrete altitudes was also performed. Figure 4 displays the percent of valid data records at discrete altitudes and shows that data availability for the original FC data increased from 75% at 100 m (328 ft) to 93% at 800 m (2,625 ft) then gradually decreased to 22% at 5,000 m (16,404 ft). The availability of the updated FC data was 95% at 100 m (328 ft) and peaked at 98% from 800 m (2,625 ft) to 1,500 m (4,921 ft) then decreased to 33% by 5,000 m (16,404 ft). With the updated QC method, data availability was higher for the entire profile compared to the original QC method. MSFC NE expected this attribute, as the purpose of implementing the modified QC method was to allow more data to be classified as valid, especially at low altitudes.

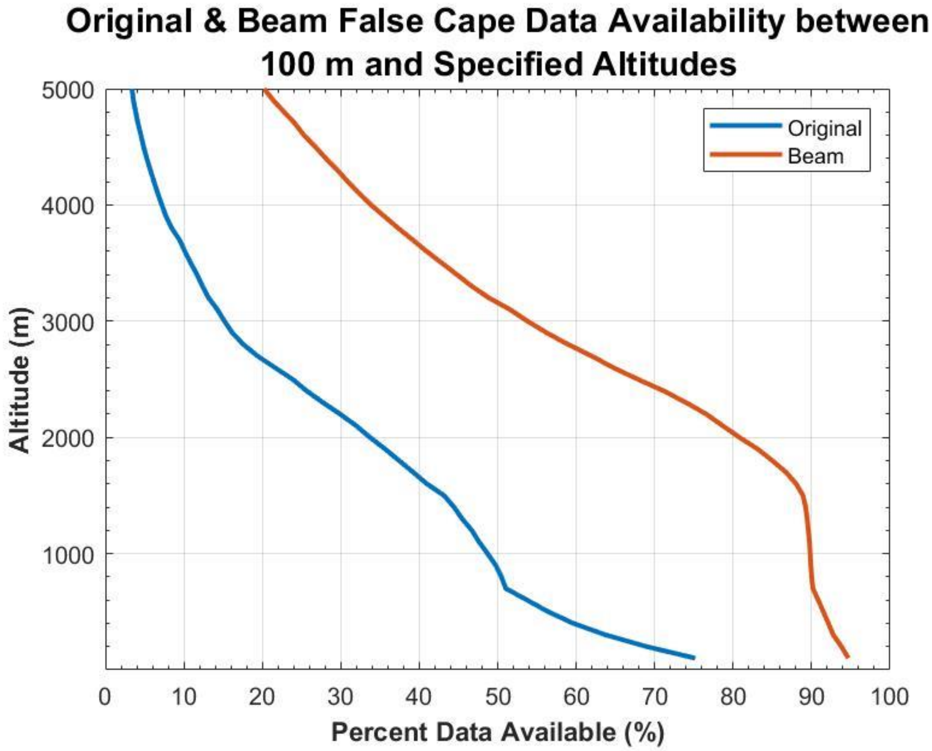

Figure 3: Percent of profiles containing no missing data from 100 m (328 ft) to the altitude specified on the ordinate.

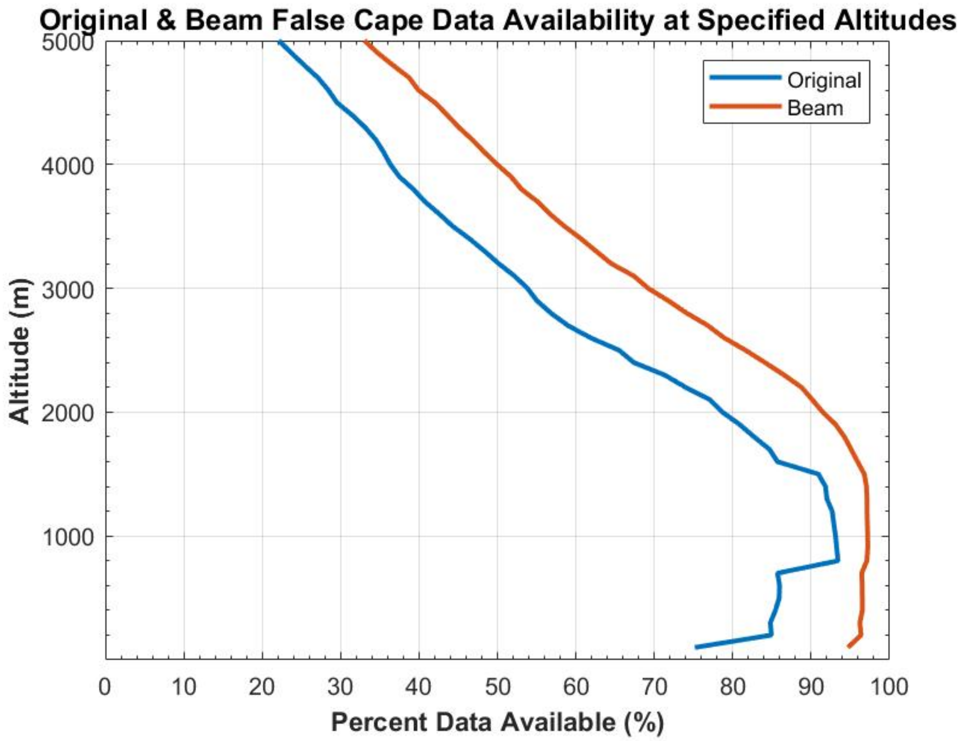

Figure 4: Percent of the DRWP archive that contains data records at discrete altitudes.

Time-height section plots were created for each day within the POR for the DRWP data to visualize how much more data was retained using the updated QC method and to determine if the data passing the updated QC method appeared to be in family with surrounding reports. Sets of two-row, three-column images of the DRWP's U component and V component from both QC methods, as well as the difference between U and V using the two QC methods (ΔU and ΔV), were generated for each day in the POR. Figure 5 is an example plot from November 16, 2020. There exists a notable increase in both the U and V wind component data in the beam data (top and bottom center respectively) compared to the original data (top and bottom left). The highest values of ΔU and ΔV for this day of roughly +/- 2.0 m/s are concentrated between 800 m (2,625 ft) and 1,500 m (4,921 ft).

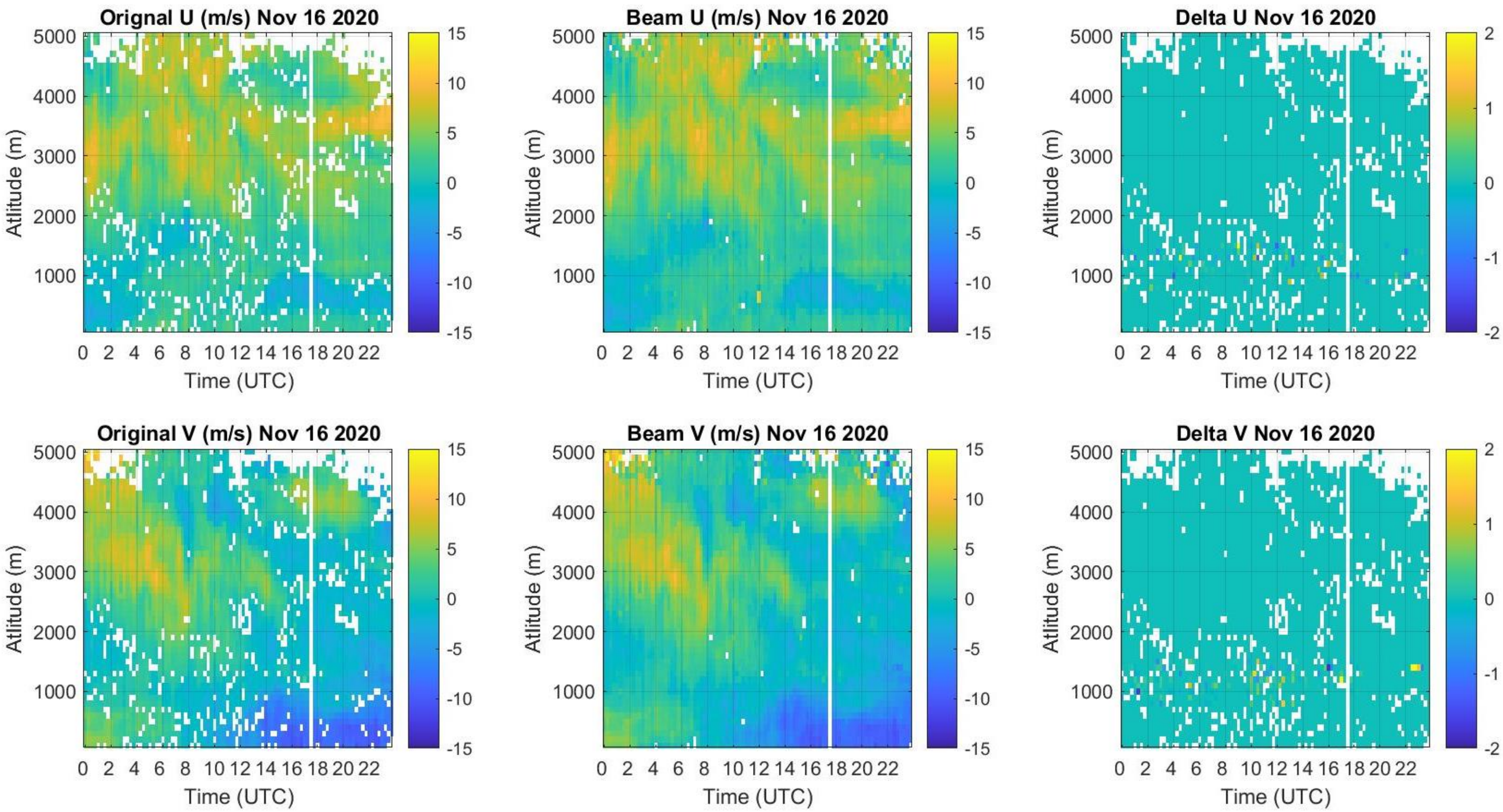

Figure 5: U component for original DRWP data (m/s, top left), U component for beam DRWP data (m/s, top center), ΔU (top right), V component for original DRWP data (m/s, bottom left), V component for beam DRWP data (m/s, bottom center), and ΔV (bottom right) for November 16, 2020.

3.2. Comparison of Wind Profiles with both QC methods

MSFC NE statistically compared wind profiles from the DRWP with both the original and updated QC method. A total of 210 days' worth of data was used resulting in 19,879 profiles being used to compute statistical quantities of wind component, vector wind magnitude, and wind direction deltas versus altitude (AGL) between the two data sets. First, wind component deltas were generated as

$$\Delta U = U_{Org} - U_{Beam}, \text{ and} \tag{1a}$$

$$\Delta V = V_{Org} - V_{Beam} \tag{1b}$$

where subscripts "Org" and "Beam" denote the original QC method and updated (beam) QC method wind component. Next, the vector wind magnitude delta, $\Delta\vec{V}$, was computed as

$$\Delta V = \sqrt{\Delta U^2 + \Delta V^2}. \tag{2}$$

Last, the wind direction delta, $\Delta\theta$, was computed as the smallest angle between the original and beam wind vectors. The cosine of this quantity is defined as the vectors' dot product divided by the product of their magnitudes, which equates to

$$\Delta\theta = cos^{-1}\left(\frac{U_{Org}*U_{Beam}+V_{Org}*V_{Beam}}{WS_{Org}*WS_{Beam}}\right) \tag{3}$$

where WS_{Org} and WS_{Beam} denote the wind speed from the original and beam data, respectively.

MSFC NE computed these quantities to statistically characterize the differences between original and beam data. At each altitude, the mean and root-mean-square (RMS) of ΔU, ΔV, and Δθ were computed.

The mean deltas of each quantity, shown in Figure 6, provide an estimate of bias of the DRWP. The left panel displays the mean wind component deltas. The mean ΔU and mean ΔV remained close to 0 m/s (0 ft/s) for most of the profile with the exception between 800 – 1,500 m (2,625 – 4,921 ft) where values were slightly above or below 0 m/s (0 ft/s), ranging from -0.0116 – 0.0136 m/s (-0.0381 – 0.0446 ft/s). The center panel shows the mean vector delta. This quantity stayed at 0 m/s (0 ft/s) for most of the profile except for increasing to 0.118 m/s (0.387 ft/s) at 800 m (2,625 ft), peaking at 0.2192 m/s (0.7192 ft/s) at 1,500 m (4,921 ft) and decreasing to 0 m/s (0 ft/s) at higher altitudes. The right panel presents the mean Δθ versus altitude, which remained at 0° for most of the profile, except when increasing to 0.8052° at 800 m (2,625 ft), peaking at 1.395° at 1,500 m (4,921 ft) then decreasing to 0°. This analysis of Δθ was performed ignoring the relationship between wind direction and wind speed.

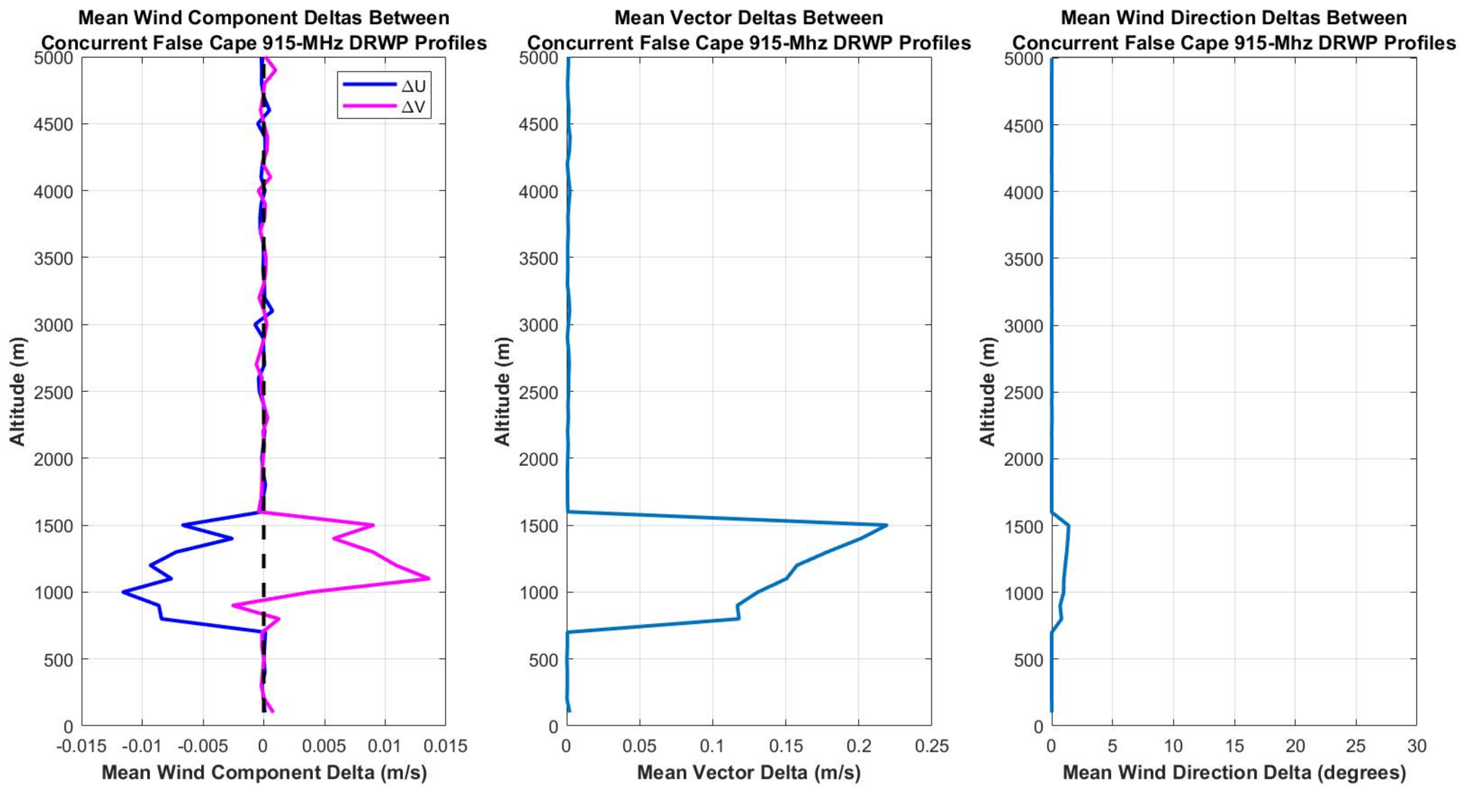

Figure 6: Mean deltas of wind components (m/s, left), vector magnitude (m/s, center), and wind direction (degrees, right) versus altitude (AGL) between concurrent data from the False Cape 915-MHz DRWP.

The RMS deltas of each quantity, shown in Figure 7, provided an estimate of the error of each data set. The left panel displays the RMS wind component deltas. Most of the RMS deltas of both wind components remained close to 0 m/s (0 ft/s) with an increase to 0.4 m/s (1.3 ft/s) at 800 m (2,625 ft), peaking at 0.5 m/s (1.6 ft/s) at 1,500 m (4,921 ft), then dropping back down close to 0 m/s (0 ft/s). For the rest of the profile both wind components stay at or below 0.1 m/s (0.3 ft/s). The center panel shows the RMS vector delta. This quantity was near 0 m/s (0 ft/s) at the lowest altitudes, then increased to 0.5662 m/s (1.8576 ft/s) at 800 m (2,625 ft), peaking at 0.7336 m/s (2.4068 ft/s) at 1,500 m (4,921 ft). Above 1,500 m (4,921 ft), the value stays below 0.1 m/s (0.3 ft/s). The right panel presents the RMS Δθ versus altitude, which starts at 0°, then increased to 4.46° at 800 m (2,625 ft) and peaked at 5.793° at 1,500 m (4,921 ft) before returning to 0°. There are two higher altitudes with a slight increase in Δθ: the first being at 2,300 m (7,546 ft) increasing to 1.035° and at 3,100 m (10,171 ft) to 0.7588°. As with the analysis of mean Δθ, this analysis of Δθ was performed ignoring the relationship between wind direction and wind speed.

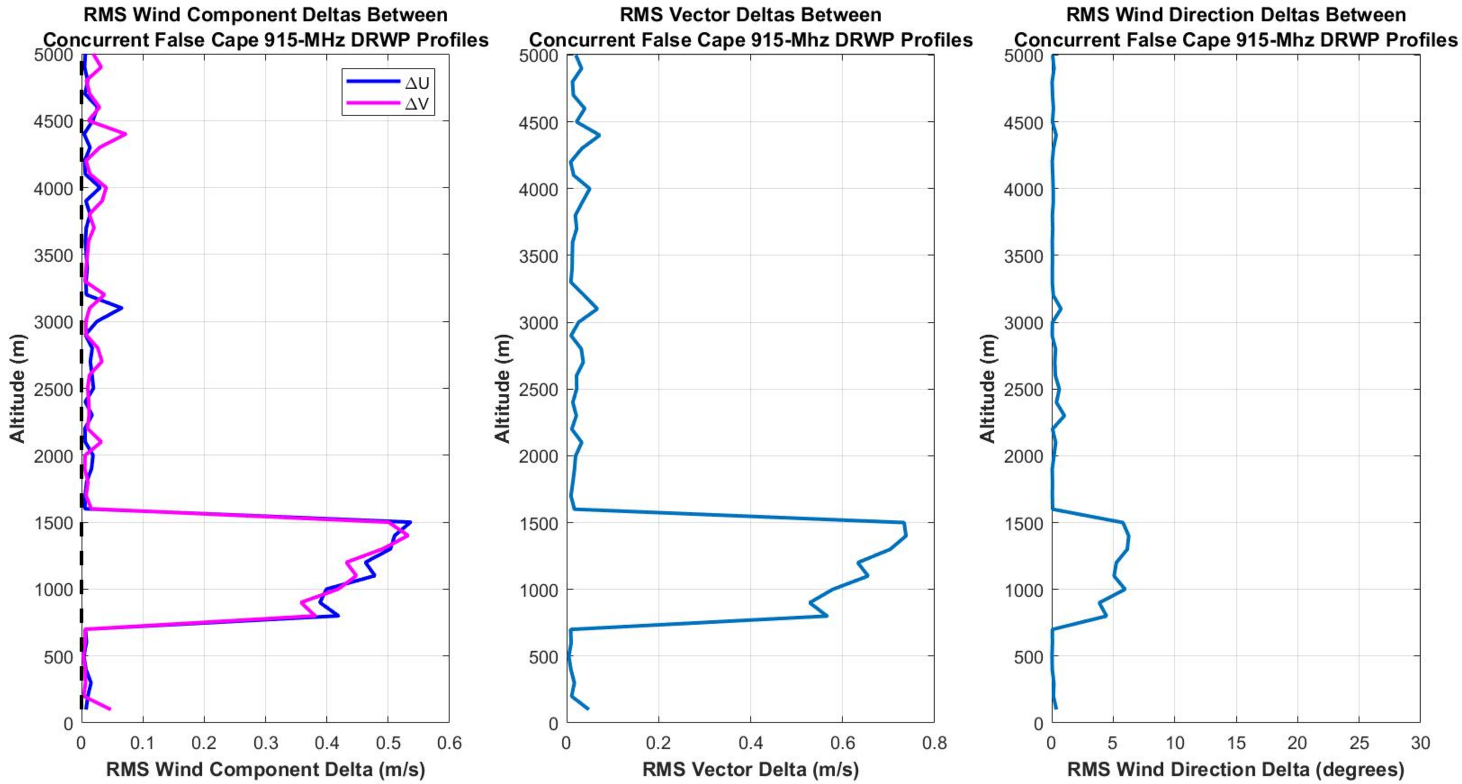

Figure 7: RMS deltas of wind components (m/s, left), vector magnitude (m/s, center), and wind direction (degrees, right) versus altitude (AGL) between concurrent data from the False Cape 915-MHz DRWP.

4. Summary

This report documents analyses conducted to evaluate wind profile output from the FC 915-MHz DRWP using two different QC methods. Wind profile measurements from October 17, 2020 to January 26, 2021 were used. Analyses included comparing data availability and wind components from both data sets.

The biggest increase in data availability exists in the lower altitudes, with at 20% increase in data at 100 m (328 ft) although there was still a 17% increase in data at 5,000 m (16,404 ft) in the beam DRWP data compared to the original DRWP data.

The mean ∆U and mean ∆V remained close to 0 m/s (0 ft/s) for most of the profile except between 800 – 1,500 m (2,625 – 4,921 ft) where values ranged from -0.0116 – 0.0136 m/s (-0.0381 – 0.0446 ft/s). The mean vector delta stayed at 0 m/s (0 ft/s) for most of the profile except for increasing to 0.118 m/s (0.387 ft/s) at 800 m (2,625 ft), peaking at 0.2192 m/s (0.7191 m/s) at 1,500 m (4,921 ft) before decreasing back to 0 m/s (0 ft/s). The mean ∆θ versus altitude remained at 0° for much of the profile, except when increasing to 0.8052° at 800 m (2,625 ft), peaking at 1.395° at 1,500 m (4,921 ft) then decreasing back to 0°.

Most of the RMS deltas of both wind components remain close to 0 m/s (0 ft/s) with an increase to around 0.4 m/s (1.3 ft/s) at 800 m (2,625 ft), peaking near 0.5 m/s (1.6 ft/s) at 1,500 m (4,921 ft), then decreasing back to values close to 0 m/s (0 ft/s). For the rest of the profile both wind components stay at or below 0.1 m/s (0.3 ft/s). The RMS vector delta started near 0 m/s (0 ft/s) at the lowest altitudes, then increased to 0.5662 m/s (1.8576 ft/s) at 800 m (2,625 ft), peaking at 0.7336 m/s (2.4068 ft/s) at 1,500 m (4,921 ft). Above 1,500 m, the value stays below 0.1 m/s (0.3 ft/s). The RMS Δθ versus altitude starts off at 0°, then increased to 4.46° at 800 m (2,625 ft) and peaked at 5.793° at 1,500 m (4,921 ft) before returning to 0°.

4. Acknowledgements

Much appreciation goes to numerous personnel at multiple organizations who helped with this project. Don Pinter / RGNext supplied the data from all the DRWP and balloon systems at the ER. Frank Leahy / MSFC NE obtained much of the data used for this study and coordinated scope and schedules with RGNext. Suzanne Siverling / RGNext served as the Technical Point of Contact during this study, and graciously addressed several questions about the data. Many thanks go to the reviewers of this report. This work was performed under contract 80MSFC18C0011.

5. References

MSFC NE. “Performance Assessment of the Eastern Range False Cape 915-MHz Doppler Radar Wind Profiler.” NASA Memorandum EV44 (21-002). February 18, 2021.